EF MC/Simulation Overview

John Stupak
on behalf of the EF MC Task Force

9/21/20

Snowmass 2013

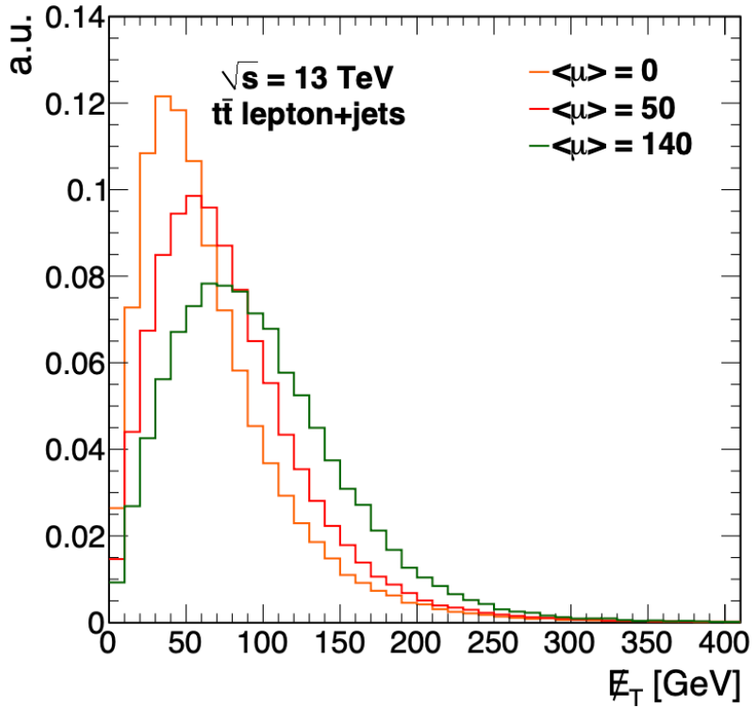
- Ran MadGraph5 + Pythia6 + Delphes3 opportunistically on the OSG to produce large-statistic SM background MC samples for future pp colliders

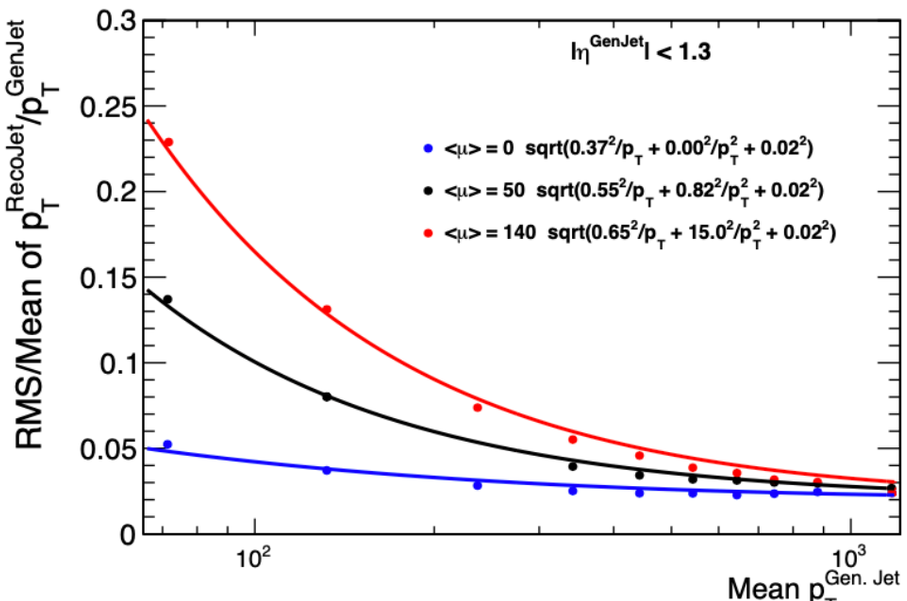
Parameter	LHC	HL-LHC	HE-LHC	VLHC
Energy [TeV]	14	14	33	100
Mean additional interactions per crossing ($< \mu >$)	50	140	140	140
Integrated Luminosity [fb^{-1}]	300	3000	3000	3000

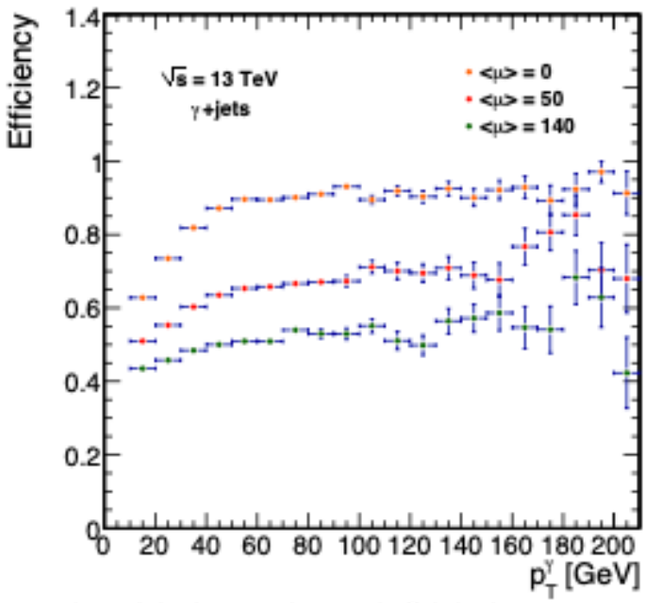
- Documentation:
  - MC Simulation: https://arxiv.org/abs/1308.1636
  - “Snowmass” detector: https://arxiv.org/abs/1309.1057
  - OSG production: https://arxiv.org/abs/1308.0843

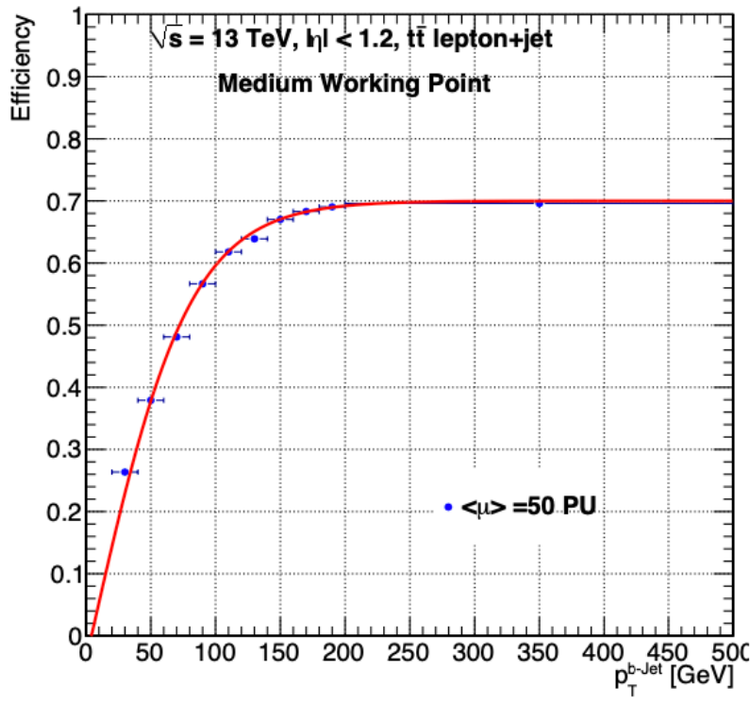
Snowmass 2013

- "Snowmass detector" implemented in Delphes
  - The best of both ATLAS and CMS
    - Performance taken from public documents, reflecting expected future upgrades
- Main simulation parameters (generally specified as p_T- and η-dependent functions):
  - Tracking efficiency (charged hadrons, e, μ)
  - Momentum resolution (charged hadrons, e, μ)
  - Calorimeter resolution (EM, hadronic clusters)
  - Reconstruction/tagging efficiency (e, μ, γ, b-jet, τ_h)
- Isolation determined by simulation
- PU suppression: charged hadron subtraction and area-based correction
- Developed new functionality (output slimming, jet grooming/substructure, t/V/H-tagging)









Snowmass 2021

Machine	Energy							
linear ee	250	350	380	500	1000	1500	3000	GeV
circular ee	m_Z	$2m_W$	240	$2m_t$				
FCC-hh	75*	100	150*					TeV
LHeC/FCC-eh	1.3	3.5						
μμ	3	10	14	30				

ILC
CLIC
CEPC/FCC-ee
FCC-ee

*supplemental WPs

- Landscape has evolved
  - Simulation frameworks consist of varying levels of sophistication
- Wide variety of studies planned for Snowmass
  - Requiring varying levels of simulation accuracy (full sim, fast sim, truth)
- EF MC Task Force formed to:
  - Survey existing frameworks and MC samples
  - Assess the needs for additional MC samples/production
  - Develop recommendations/plan for additional MC production
    - To be implemented by EF MC Production team

EF MC Task Force

- Background, charge, etc
- wiki
- Membership:

Name	Institution	email	
John Stupak (chair)	University of Oklahoma	john.stupak[at]cern.ch	Snowmass2013
Robert Gardner	University of Chicago	rwg[at]uchicago.edu	OSG rep.
Simone Pagan Griso	LBNL	spagangriso[at]lbl.gov	BSM rep.
Stefan Hoeche	FNAL	shoeche[at]fnal.gov	MC expert
Fabio Maltoni	CP3, Catholic University of Louvain	maltoni.fabio[at]gmail.com	MC expert
Meenakshi Narain	Brown University	meenakshi.narain[at]cern.ch	EF convener
Isabel Ojalvo	Princeton University	isabel.rose.ojalvo[at]cern.ch	EWK rep.
Laura Reina	Florida State University	reina[at]hep.fsu.edu	EF convener
Michael Schmitt	Northwestern University	m-schmitt[at]northwestern.edu	QCD rep.
Alessandro Tricoli	Brookhaven National Laboratory	atricoli[at]bnl.gov	EF convener

MC/Simulation Info

Full Simulation

Delphes

Which proposed collider are you responding on behalf of?	Have you developed a simulation framework based on GEANT?	Is this framework publicly-available? If so, where?	Have you developed a DELPHES detector card (or other form of fast and/or parameterized simulation)?	Is this card publicly-available? If so, where?
ILC	Yes.	https://github.com/iLCSoft	Work is currently ongoing.	https://github.com/ILDAnaSoft/ILDDelphes (still WIP)
CLIC	Yes, DD4hep+DDG4+ddsim	e.g: /cvmfs/clicdp.cern.ch/iLCSoft/builds/2020-02-07/x86_64-slc6-gcc62-opt/init_ilcsoft.sh github.com/aidasoft/dd4hep	yes, CLICdet cards Stage1/2/3, documentation in https://twiki.cern.ch/twiki/bin/view/CLIC/DelphesMadgraphForBSMReport and https://arxiv.org/abs/1909.12728 (contains concrete instructions)	Yes in the delphes code
CEPC	Yes, CEPC has the Mokka-C, a Geant-4 Full simulation toolkit.	The CEPCsoft are capsuled into a package on cvmfs, the installation can be found at http://cepcsoft.ihep.ac.cn/guides/scratch/docs/cvmfs/	Yes, we have developed a Delphes card, which is also validated on the Full simulation tools. In addition, many small fast simulation tools are developed.	The Delphes card is public available, see https://arxiv.org/abs/1712.09517.
FCC-ee	Yes	Yes, the code is on github: https://github.com/HEP-FCC/ and it is installed centrally on cvmfs (same as FCC-ee). Also for the CDR, full simulation samples where produced with CMSSW.	Yes	Yes, several cards for e+e- detector concepts are available on the delphes GitHub (https://github.com/delphes/delphes/tree/master/cards/).
FCC-hh	yes	Yes, the code is on github: https://github.com/HEP-FCC/ and it is installed centrally on cvmfs	yes	Yes, it is available for FCC-hh on the FCCSW website http://hep-fcc.github.io/FCCSW/
LHeC/FCC-eh	Yes: DD4HEP interface to GEANT	Yes: http://dd4hep.web.cern.ch/dd4hep/	Yes	Not yet
Muon collider	Yes	yes, github	No DELPHES, no parametric simulation	no

Available here:
https://docs.google.com/spreadsheets/d/19KWScsrEgmHRBtqq3tKxHiREEbT0e_IC3DIPcTdEixc/edit?usp=sharing

MC/Simulation Info

MC Access

Which proposed collider are you responding on behalf of?	What signal/background MC samples have been produced thus far (using either fast or full simulation)?	Where are they located?	Can they be accessed by external collaborators? If so, how?
ILC	generator-level event samples, stdhep format for √s = 250GeV, 350 GeV, 500 GeV, 1 TeV, further samples based on fast simultion (SGV) and full simulation (iLCSoft) are in preparation	On the GRID under VO ILC	If they have access to VO ILC. For full simulation samples an ILD or SiD guest membership will be required.
CLIC	See: https://twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForCLICdet	CERN EOS Storage	Access can be granted for CERN account holders, membership to the ILC VO can probably be granted without too much hassle. Files could be transfered to other StorageElements if they allow the ILC vo access, if that would help
CEPC	We have full simulation of CEPC ZH and SM background at 240GeV, 350GeV, and Z pole events. See CEPC Note http://cepcdoc.ihep.ac.cn/DocDB/0002/000203/002/CEPCNoteCover.pdf	With the support of the computing center of Institute of High Energy Physics, the CEPC samples are stored on the IHEP clusters.	Currently, an IHEP account is needed to access these samples. You can contact us and we will be happy to apply an account for you.
FCC-ee	A limited number of useful e+e- event samples, processed through full CMS simulation and reconstruction, still exist (though producing again these events won't take very long).	On private areas	Possibly on demand, in a way to be defined
FCC-hh	Full and Delphes samples are listed here http://fcc-physics-events.web.cern.ch/fcc-physics-events/Delphesevents_fcc_v02.php http://fcc-physics-events.web.cern.ch/fcc-physics-events/FCCsim_v03.php	There are located on eos at CERN	Yes, either by subscribing to dedicated e-groups at CERN, or could setup web based but less prefered
LHeC/FCC-eh	Signal: several Higgs decay modes plus backgrounds	CERN and University servers	Possibly upon request
Muon collider	Higgs to bb and b backgrounds	University of Padova Cloud	Yes

Available here:
https://docs.google.com/spreadsheets/d/19KWScsrEgmHRBtqq3tKxHiREEbT0e_IC3DIPcTdEixc/edit?usp=sharing

MC/Simulation Info

Documentation & Contacts

Which proposed collider are you responding on behalf of?	Is any documentation available to facilitate analysis of these samples?	Who within the collaboration should members of the Energy Frontier contact with further questions regarding MC/simulation frameworks?	Is there some place where additional information related to MC/simulation frameworks can be found?
ILC	In preparation.	jenny.list@desy.de	https://arxiv.org/abs/2007.03650
CLIC	LCIO API lcio.desy.de, The full simulation is based on the Marlin framework using LCIO for input output. The collections *SelectedPandoraPFOs contain reconstructed particle flow objects that can be used as input to JetClustering, Vertexing or Flavourtagging, depending on the requirements of the analysis. LCFIPlus (https://github.com/lcfiplus/LCFIPlus), FastJet(https://github.com/iLCSoft/MarlinFastJet)	Please contact us at clicdp-snowmass-samples-contacts@cern.ch	https://arxiv.org/abs/1812.07337 contains a section on the software, github.com/ilcsoft
CEPC	Yes, the samples description can be found in http://cepcdoc.ihep.ac.cn/DocDB/0002/000203/002/CEPCNoteCover.pdf. There is also a CEPC software webpage (http://cepcsoft.ihep.ac.cn), describing the overview of all the softwares we use and some illustration. A CEPC notes database (http://cepcdoc.ihep.ac.cn/cgi-bin/DocDB/DocumentDatabase) with plenty of existing analysis can be also used as an indication.	manqi.ruan@ihep.ac.cn, ligang@ihep.ac.cn, yudan@ihep.ac.cn.	
FCC-ee	No	gerardo.ganis@cern.ch, clement.helsens@cern.ch, patrick.janot@cern.ch, patrizia.azzi@cern.ch	Same as FCC-hh (https://cds.cern.ch/record/2717892)
FCC-hh	Yes, https://cds.cern.ch/record/2717892	Michele.Selvaggi@cern.ch, gerardo.ganis@cern.ch, clement.helsens@cern.ch	Yes, https://cds.cern.ch/record/2717892
LHeC/FCC-eh	Only in talks at workshops	oliver.fischer@liverpool.ac.uk	No
Muon collider	Yes	donatella lucchesi (donatella.lucchesi@pd.infn.it)	https://sites.google.com/site/muoncollider/home

Available here:
https://docs.google.com/spreadsheets/d/19KWScsrEgmHRBtqq3tKxHiREEbT0e_IC3DIPcTdEixc/edit?usp=sharing

General Plan (WIP)

- Full simulation
  - Facilitate access to existing samples, hosted by various collider efforts
  - Facilitate or negotiate production of any additional samples required
- Fast simulation
  - Generate samples with Delphes (on demand)

Machine	Energy							
linear ee	250	350	380	500	1000	1500	3000	GeV
circular ee	m_Z	$2m_W$	240	$2m_t$				
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LHeC/FCC-eh	1.3	3.5						
μμ	3	10	14	30				

ILC
CLIC
CEPC/FCC-ee
FCC-ee

*supplemental WPs

Community Survey

- Still open, please provide your input!
  - If your plans evolve/crystalize later, responses are editable

https://forms.gle/RMxeXXKcjvPbHicTA

Snowmass Energy Frontier MC Task Force - Community Survey

The success of the Snowmass Energy Frontier effort depends crucially on the analysis of a wide variety of MC samples for various future colliders/detectors. Collaborations for future collider proposals have produced many such samples, using simulation frameworks of varying degrees of sophistication. However, production of additional samples may be necessary to conduct proposed studies for Snowmass 2021.

The purpose of this form is to gather community input regarding the necessity and availability of MC samples for Snowmass 2021. This information will be used to determine if a centralized effort to produce MC samples is required, and if so, how to maximize the utility of the resulting MC (within computing and other constraints).

Before completing this survey, please review the following google doc, which summarizes the current availability of MC samples for various proposed machines: https://docs.google.com/spreadsheets/d/19KWScsrEgmHRBtqq3tKxHiREEbT0e_lC3DIPcTdEixc/edit?usp=sharing

*Required

Email address *

Your email address

What is your name? *

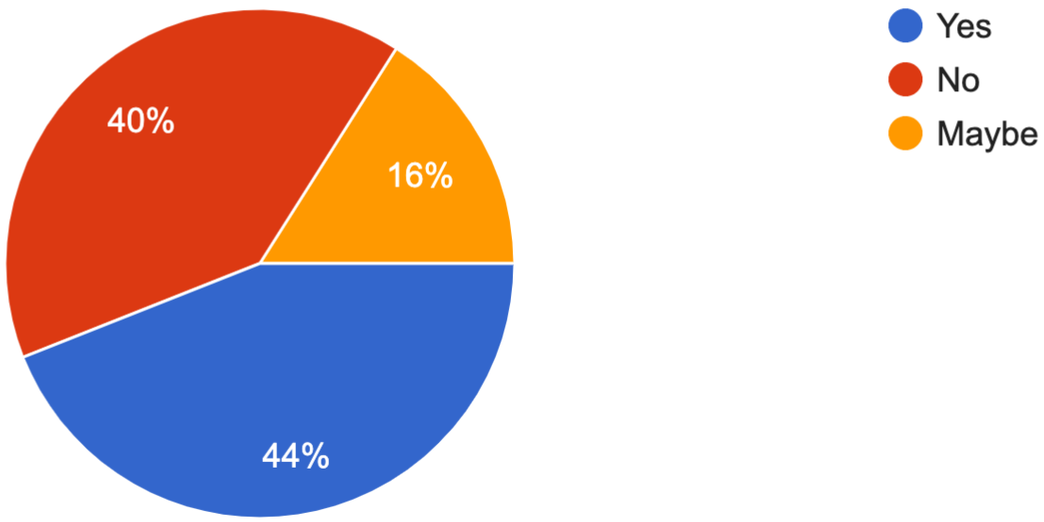
Your answer

Which topical groups might your planned studies fall within? *

- [ ] EF01: EW Physics: Higgs Boson properties and couplings
- [ ] EF02: EW Physics: Higgs Boson as a portal to new physics

Do you identify as a member of Snowmass young?

25 responses



MC/Simulation Tutorials

- **Hands on**
- Led by experts from within the collaborations
- Covering:
  - Available MC samples
  - Structure of the MC
  - Signal MC generation
  - Analysis examples
  - …
- Please register and attend!
- Recordings made available ASAP
- Please let me know if there are any additional topics you would like to have covered

Machine	Date
ILC	Aug 28
CEPC	Sept 8
FCC-ee/hh	Sept 22-23
LHeC/FCC-eh	Sep 25
Whizard for e+e-	Sept 28
FCC-ee/hh	Sept 29
Muon Collider	Sep 30

links available from wiki

Computing Resources

- OSG has kindly offered to support Snowmass community and supply computing resources for those in need
  - Interactive login node + batch (opportunistic) job submission + storage
    - Request an account: https://connect.snowmass21.io/
    - Documentation: https://maniaclab.uchicago.edu/snowmass-connect-docs/
    - Support, announcements, etc: https://snowmass2021.slack.com/archives/C019UAV3YQL

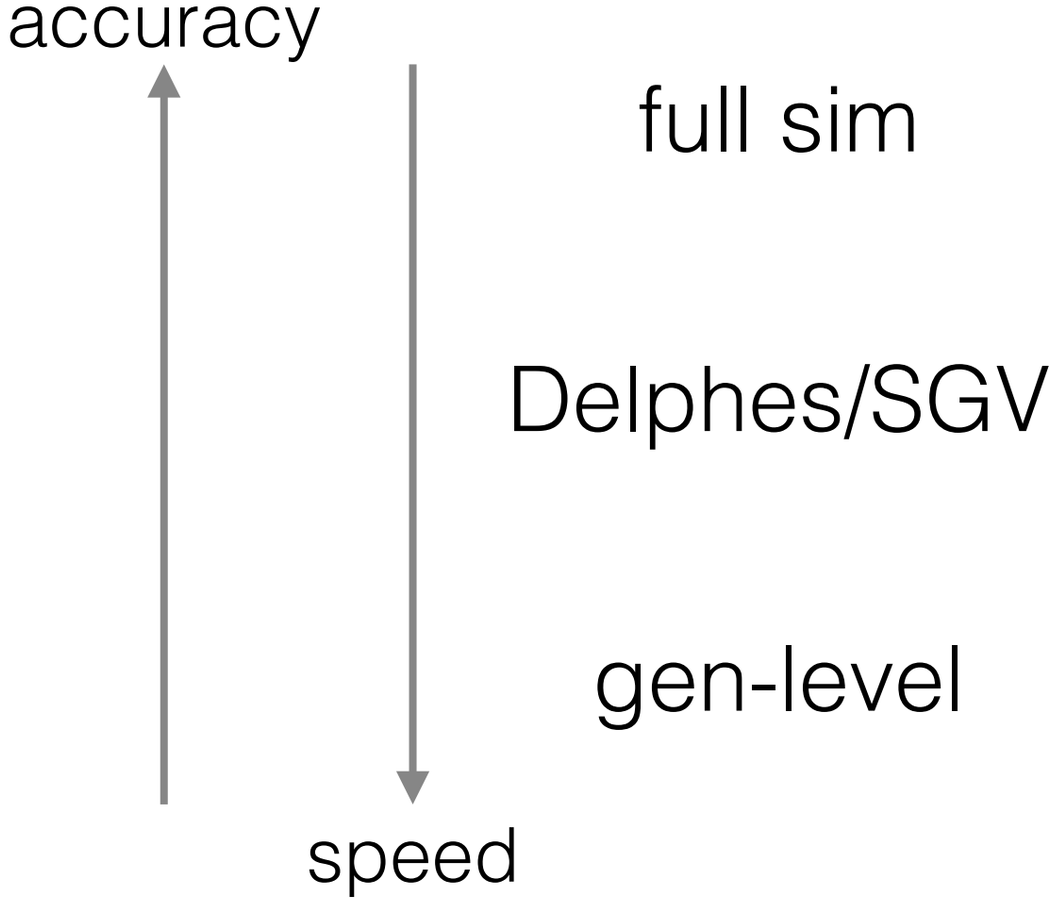
Conclusion

- MC TF is here to help you conduct your Snowmass studies
  - Please let the us/me know if there is anything you need, which is not already available
    - Information/instruction
    - MC samples
    - Computing
    - …

Backup

MC Simulation

- Wide variety of studies anticipated within EF
  - Different types of MC needed for different purposes



[Narain]

Charge of the EF MC Task Force (I)

1. Assess the MC needs for studies by each Energy Frontier Topical Group.
   a. This should include the processes, the MC generators, the accelerator configurations (c.o.m, integrated luminosity, pileup scenarios, if any), detector configurations, and number of events for each process type.

Community Survey

2. Survey existing frameworks for MC generation and analysis for future circular colliders (FCC-ee, FCC-hh, CepC, CppC, LHeC, EIC...etc...).
   a. Are the existing samples and framework sufficient for our studies?
   b. Need to request permission to use the existing samples?
3. Check/confirm that ILC, CLIC, Muon collider studies will use their frameworks, and no MC generation by EF group needs to be planned.

Collaboration Survey

4. Finalize the plans and submit the recommendations by the end of June 2020 to the EF conveners.
5. The plan and recommendations will be presented to the EF community and discussed during the July 2020 EF Workshop.
6. The OSG has kindly agreed to support the MC generation for EF, and will provide both compute resources and storage on the OSG Data Federation.

Work In Progress

8

collaboration and community surveys distributed on May 31

[Narain]

Charge of the EF MC Task Force (II)

7. **Develop a plan,** in the event the EF group has to mount a production of a large set of samples for Standard Model backgrounds. The plan should address the following questions:

   a. Shall we adopt a "common framework" both for generation & analysis of the various samples, if so, which one(s)?
   b. Which samples are needed to be produced as a central production?
      i. Include detailed information about the samples (as listed in 1.a above).
      ii. Should signal samples be produced by the proponents and only large SM background samples be produced centrally?
   c. What scale of CPU resources are needed for sample generation?
   d. What projected size of storage is required for production and long term storage of the samples?
   e. Recommendation on the formation and activities of the "EF Monte Carlo Production team".

Work In Progress

Community Survey

Work In Progress

9

collaboration and community surveys distributed on May 31

Grossly Oversimplified Results

	Full Sim	Delphes	Extensive Bkgd MC	Publicly Available	Take Requests
ILC	✅	⚠️ Not yet, but SGV	✅	⚠️ "guest" membership available	⚠️
CLIC	✅	✅	✅	🚫 ILC VO	⚠️
CEPC	✅	✅	⚠️	⚠️ IHEP account required	✅
FCC-ee	✅	✅	🚫	🚫 Possibly in the future	✅
FCC-hh	✅	✅	✅	✅ CERN account required	✅
FCC-eh/LHeC	✅	✅	⚠️	⚠️ "Light" membership available	✅
Muon Collider	✅	🚫	🚫	⚠️ INFN Padova account required	✅

Snowmass 2013

Snowmass 2013

- Signal MC production isn't resource intensive
  - Provided analysts with recipe for production from LHE, as well as analysis pointers
- Studies for ILC, CLIC, etc. used their own frameworks/ samples
- Common data format for all future pp machines facilitated easy analysis/comparison
  - Tune a few cuts and turn the crank
- These samples were useful well beyond Snowmass itself
  - I am still occasionally asked if they are accessible

Challenge

- σ_{ttbar} @ 14 TeV = 1 nb
  - For L_{eff} = 10 * 3/ab: N = 3E10
    - 1 kB/event → 30 TB
    - 1 minute/event → 50k CPU·years
- Generated weighted events to reduce statistics required by ~2000x
- Used parameterized detector simulation to reduce CPU consumption to manageable level
- Utilized opportunistic OSG resources

Event Generation

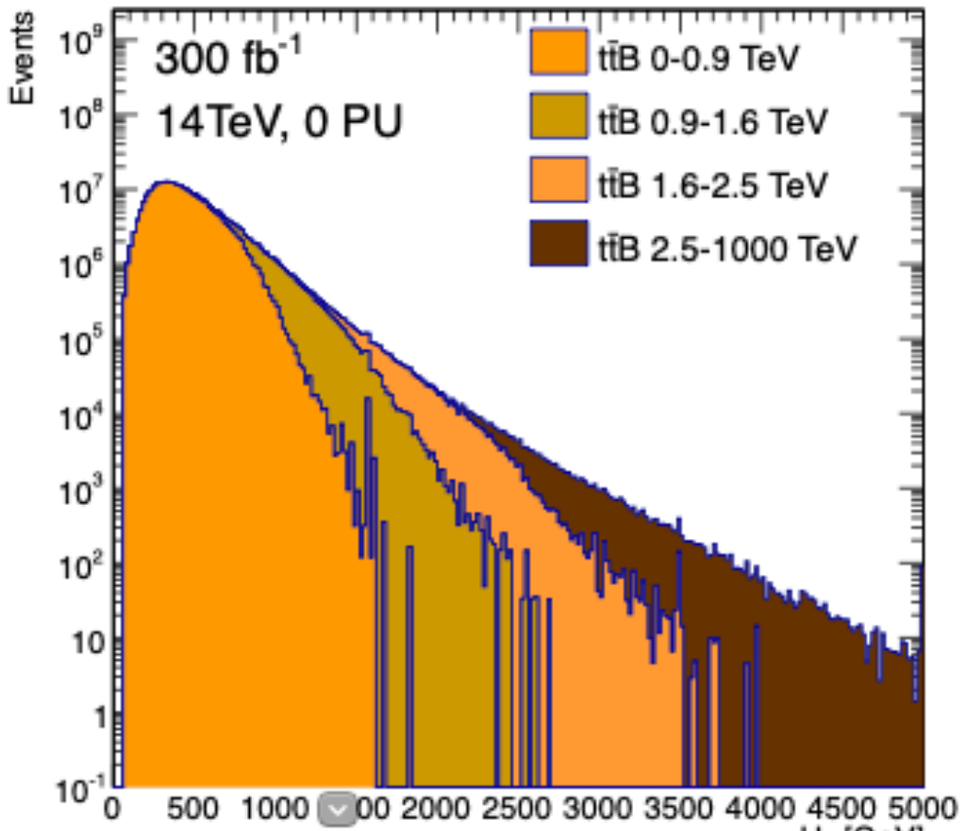
- With many background processes and E/PU combinations, adopted "container" scheme to simplify organization/book-keeping
  - Combined processes with similar cross sections in single MC sample
    - On-shell internal propagators excluded → fully orthogonal
  - On-shell heavy resonances treated as stable (decayed later w/ BRIDGE)
  - Up to 4 final state partons
- Each sample was binned in S_T^*: scalar p_T sum of all final state partons
  - One decade of cross section per bin (up to 7)

particle containers

$$
\begin{aligned}
J &= \{g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}\} \\
L &= \{e^+, e^-, \mu^+, \mu^-, \tau^+, \tau^-, \nu_e, \nu_\mu, \nu_\tau\} \\
V &= \{W^+, W^-, Z^0, \gamma\} \\
T &= \{t, \bar{t}\} \\
H &= \{h^0\}
\end{aligned}
$$

MC samples

Dataset name	Physics process	Number of recoil jets
B-4p	γ or on-shell W, Z	0
Bj-4p	γ or on-shell W, Z	1-3
Bjj-vbf-4p	γ or off-shell W, Z, H in VBF topology	2-3
BB-4p	Diboson (γ, W, Z) processes	0-2
BBB-4p	Tri-boson (γ, W, Z) processes including BH	0-1
LL-4p	Non-resonant dileptons (including neutrinos) with $m_{ll} > 20$ GeV	0-2
LLB-4p	Non-resonant dileptons with an on-shell boson, $m_{ll} > 20$ GeV	0-1
H-4p	Higgs	0-3
tj-4p	Single top (s- and t-channel)	0-2
tB-4p	Single top associated with a boson	0-2
tt-4p	$t\bar{t}$ pair production	0-2
ttB-4p	$t\bar{t}$ associated with γ, W, Z, H	0-1



Pythia

- Five-flavor MLM matching in the shower-kt scheme

Dataset Names	QCUT
B-4p, BJ-4p, BJJ-vbf-4p, BB-4p, BBB-4p, LL-4p, LLB-4p, H-4p	40 GeV
TJ-4p, TB-4p	60 GeV
TT-4p, TTB-4p	80 GeV

Event Weight

- Generator-level events produced at LO
  - NLO k-factor calculated from ratio of MCFM and MadGraph (inclusive) cross sections
- Used BRIDGE to decay heavy resonances democratically
  - Enhances statistics for rare decay modes
- σ_{LO} * k-factor * w_{BR} stored as event weight

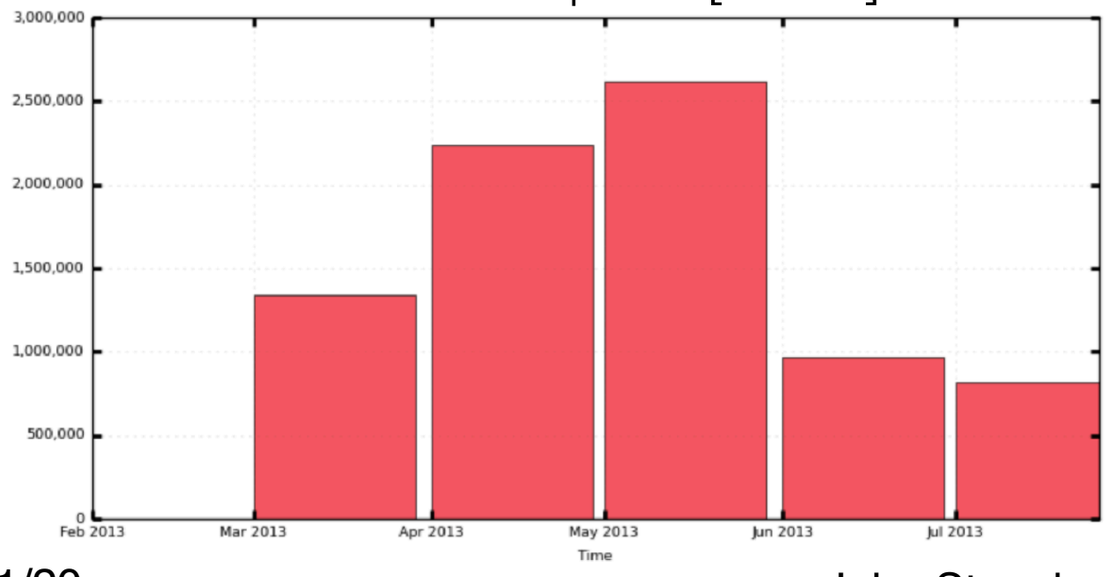
Process	$\sqrt{s} = 14$ TeV	$\sqrt{s} = 33$ TeV	$\sqrt{s} = 100$ TeV
$t\bar{t}$	1.24	1.10	0.96
$W^+ j$	1.17	0.85	0.74
$W^- j$	1.20	0.89	0.75
$Z^0 j$	1.17	0.87	0.76
γj	1.54	1.04	0.89
$W^+ W^-$	1.25	1.08	1.0
$W^+ Z^0$	1.24	1.06	0.95
$W^- Z^0$	1.26	1.09	0.97
$Z^0 Z^0$	1.37	1.29	1.21
$W^+ \gamma$	1.22	0.80	0.67
$W^- \gamma$	1.33	0.83	0.67
$Z^0 \gamma$	1.24	0.95	0.76
$\gamma\gamma$	1.34	1.08	0.98
tW^-	1.0	0.77	0.78
$\bar{t}W^+$	1.0	0.77	0.78
$t\bar{b}$	1.76	1.72	1.94
$\bar{t}b$	1.88	1.73	1.78
$\ell^+\ell^-$	1.20	1.16	1.20

$t\bar{t} \rightarrow$	weight	in sample	change
hadronic	44%	25%	0.56
semi-leptonic	44%	50%	1.13
di-leptonic	11%	25%	2.25
$W^\pm Z^0 \rightarrow$	weight	in sample	change
$1\,\ell$	30%	44%	1.4
$2\,\ell$	6.7%	11%	1.6
$3\,\ell$	3.3%	16%	4.8

Computing (OSG)

- Utilized opportunistic resources to produce ~0.5 billion events
  - ~14k jobs/day totaling ~890 CPU·years
  - Peak usage ≈ 100 kCPU·hours/day
- Job submission via GlideinWMS
- Software dependencies from CvmFS

CPU consumption [hours]



- MadGraph and Pythia/Delphes performed in 2 separate jobs
  - MadGraph
    - ~10 MB input gridpack (output LHE) transferred via HTCondor
    - Responsible for most of the CPU usage
  - Pythia/Delphes
    - 1 GB minimum bias file pre-staged to storage nodes at 10 grid sites
    - Outputs (5-20 kB/event) transferred to FNAL, BNL, UNL
      - UNL was accessible (web and XRootD) without grid certificate (theorists)

data transfer

Month	Fermi dCache (TB)	UNL (TB)
June	65.0	46.4
May	12.4	5.2
April	189.7	10.8
March	1.1	0.0
Total	268.3	62.5